Pesticide spray characterisation using high speed imaging techniques

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Pesticide spray characterisation using high speed imaging techniques

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Abstract

Spray droplet characteristics are important features of an agricultural spray. The objective of this study is to measure the droplet size for different types of hydraulic spray nozzles using a developed backlighted image acquisition system and image processing technique. An in-focus droplet criterion was established to decide whether a droplet is in focus and can be measured in an accurate way. Tests included five different nozzles (Albuz ATR orange and red, TeeJet XR 110 01, XR 110 04 and Al 110 04).

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Keywords: Spray characterization; droplet size; droplet generator; high speed imaging

1. Introduction

In recent years, advances in plant protection have contributed considerably to increasing crop yields in a sustainable way. Most of the pesticides are applied using agricultural sprayers equipped with hydraulic nozzles. These nozzles atomize the liquid into droplets with a wide droplet size range and determine the spray pattern.

In the past, various measuring techniques (Rhodes et al., 2008) have been employed in the research on spray and atomization to investigate spray characteristics including droplet sizes and velocities. Few optical measurement techniques are able to perform simultaneously a non-intrusive measurement of both droplet size and velocity: Phase Doppler Particle Analyzers (PDPA) (Nuyttens, 2007; Nuyttens et al., 2009), laser diffraction analyzers, e.g.,

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Malvern Analyzer (Stainier et al., 2006) and optical array probes (Teske et al., 2002). However, the limitations of the non-imaging techniques and the recent improvements in digital image processing, sensitivity of imaging systems and cost reductions have increased the interest in high speed imaging techniques for agricultural applications (Hijazi et al., 2012) in general and pesticide applications (Lecuona et al., 2000) in particular.

Imaging analyzers are spatial sampling techniques consisting of a light source, a camera and a computer with image acquisition and processing software. The small droplet size and high velocity of the ejected spray droplets make it a challenge to use imaging techniques for spray characterization.

This paper presents a technique based on image processing and an established in-focus droplet criterion for measuring the droplet size characteristics of agricultural hydraulic spray nozzles using an image acquisition system developed by VulgarakisMinov et al. (2015).

2. Materials and Methods

2.1. Image acquisition sytem

The image acquisition system for the development of the in-focus droplet criterion is shown in Figure 1 and has been described in detail by VulgarakisMinov et al. (2015a). The system consisted of a powerful xenon light (WOLF 5132, Knittlingen, Germany, 300 W) used as a background illumination against the droplet generator (Université de Liège, Gembloux, Agro-Bio-Tech, Belgium) combined with a N3 HS (high speed) camera (IDT, Lommel, Belgium) with a 6 µs exposure time, a K2/SC Long-Distance Microscope System Lens (Infinity, USA) and a frame capture device Motion studio (IDT, Lommel, Belgium).

The piezoelectric droplet generator was positioned at 320 mm from the xenon illumination and at a distance ranging from 420 and 430 mm from the lens. The camera, lens and illumination were aligned horizontally. A precision linear micro translation stage (Edmund Optics, 0-25 mm) with a straight line accuracy of 10 µm moveable in the Z direction was attached to the lens. The droplet generator was implemented in continuous mode (using glass nozzles with orifice sizes of 261, 123, 67, 50, and 40 µm (VulgarakisMinov et al., 2015b). These nozzle orifice sizes were chosen in order to produce a range of droplet sizes from around 100 µm up to 500 µm which is typical for most agricultural hydraulic spray nozzles.

The set-up resulted in a pixel size of 8.23 µm which made it possible to measure small droplets accurately. The images were taken in full resolution (1280 x 1024 pixels) with a field of view (FOV) of 10.5 mm x 8.4 mm at 1000 fps.

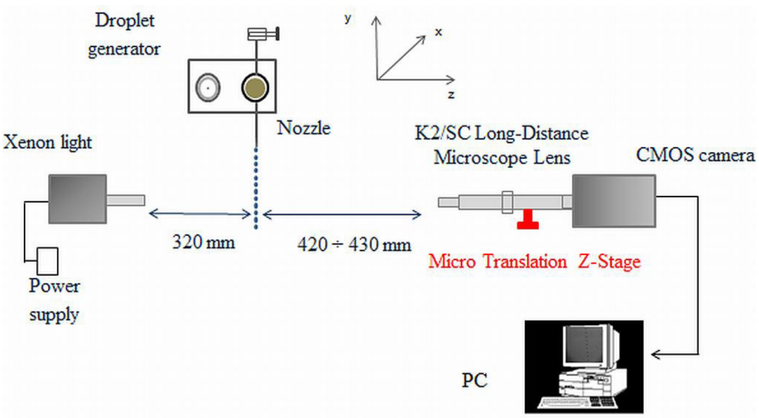

Fig. 1.Image acquisition system for establishing the in-focus droplet criterion.

2.2. Image analysis for setting up the in-focus droplet criterion

For establishing the in-focus droplet criterion, images were taken at different distances from the focal plane using all glass nozzles. This was performed by moving the translation stage (lens) towards and away from the focal plane in the range between 420 mm and 430 mm in steps of 50 µm (Figure 1).

The image analysis for setting up the in-focus criterion consisted of 3 steps: image pre-processing, image segmentation and droplet sizing, calculation of (critical) in-focus parameter and in-focus droplet criterion (Figure 2).

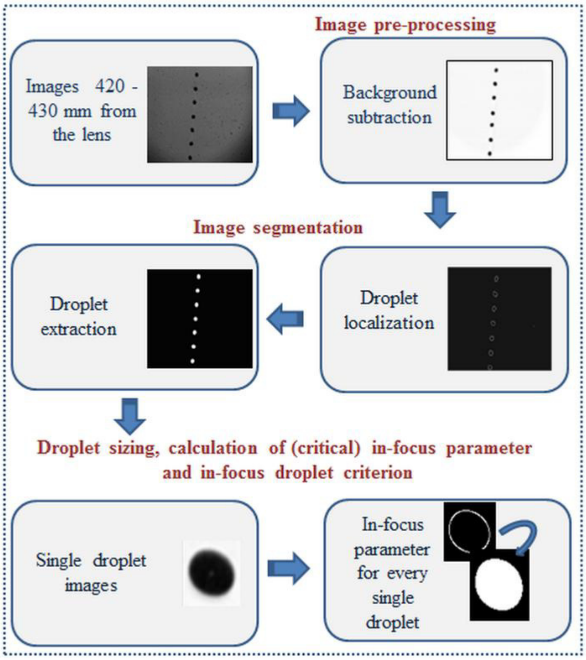

Fig. 2.Flow chart of the image analysis algorithm for establishing the in-focus droplet criterion.

Image pre-processing aims at resolving problems due to lighting patterns or dirt on the lens and was performed by background subraction from every droplet image. In addition, to increase the contrast and highlight the pixel intensity across the droplet boundaries, image normalization was done. Furthermore, image segmentation was introduced by computing the intensity gradient using a Sobel filter (Gonzalez et al., 2004). Besides, the images were binarized and the highlighted droplet contours were filled. Because the droplets were not perfectly spherical, they were considered as elliptical shapes for the diameter. Their long and short axes were measured to calculate the equivalent droplet diameter from the area (Dong et al., 2013). Finally, single droplet images of each detected droplet were derived from every droplet image. The extracted droplets did not have the same gray level intensities and edge gradients because of their different positions relative to the focal plane. Therefore, the concept of the in-focus parameter was introduced to select the in-focus droplets based on the gray level gradient, droplet diameter and gray level intensities of the background and droplet (Lecuona et al., 2000):

$$In-focusparameter = \frac{grad_{edge}}{I_{back} - I_{droplet}} * d \quad (1)$$

Where I_{back} (-) and $I_{droplet}$ (-) are image background and droplet gray level values, respectively, d is the droplet diameter (µm) and $grad_{edge}$ (-) is the gray level gradient at the droplet edge. This parameter was calculated for every detected droplet.

To separate the droplets that are in-focus from the ones out of focus, a critical in-focus parameter (Inf_c) was calculated in several steps for each droplet size. Firstly, the minimal droplet diameter was estimated from the polynomial trend line of second order using all measured droplet diameters (Fig. 3). Then, an acceptable one pixel error value to this minimal droplet diameter was set meaning that we accept a deviation of up to 1 pixel between measured and actual droplet diameter. Next, another second order polynomial curve was fit only through these droplets considered in focus with an acceptable measured droplet diameter. From this equation ($y = 0.3953\ x^2 - 336.95\ x + 71835$) and the droplet diameter of 28.6 pixels the corresponding distances to the lens were calculated (424.4 mm and 428.1 mm). Combining these distances to the lens with the second order polynomial curve through the in-focus parameters, resulted into the critical in-focus parameter value (around 6).

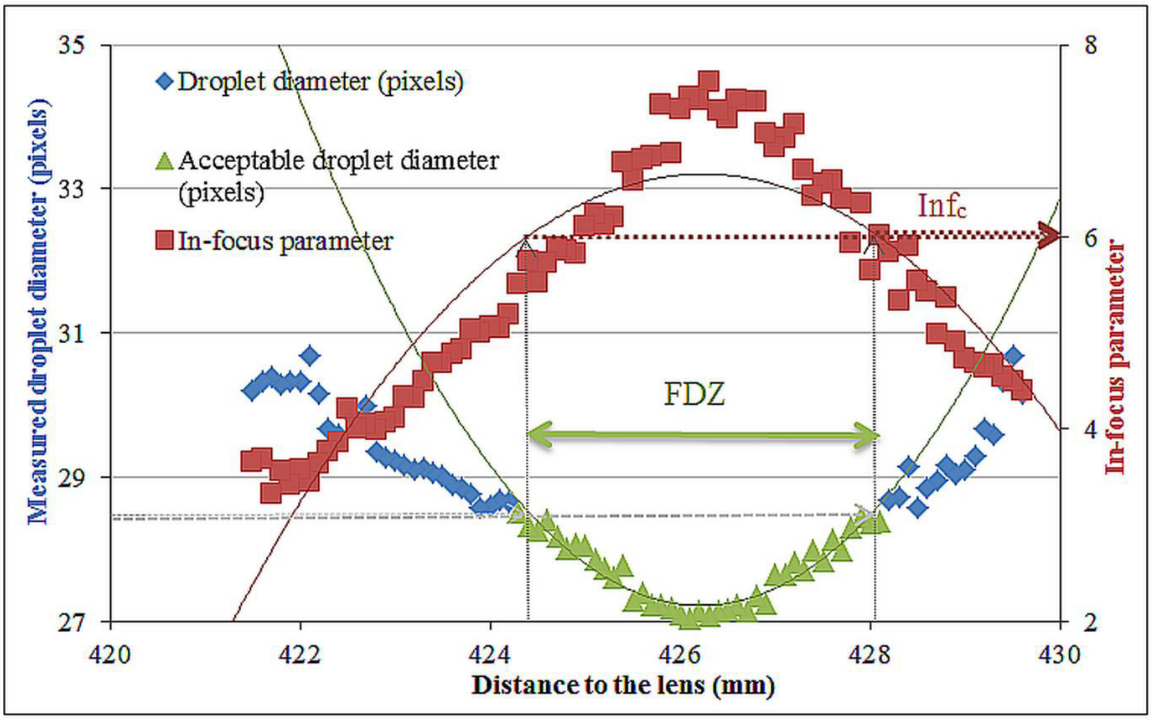

Fig. 3.Critical in-focus parameter and FDZ for images taken of the 222.9 µm droplet diameter.

All droplets with an in-focus parameter above Inf_c were considered in-focus. Besides, based on the distances from the lens at which the droplets were considered in focus, a focused droplet zone (FDZ) was defined. This is the zone around the focal plane in which droplets of a certain size are considered in-focus. For the 222.9 µm droplet size, the FDZ was 3.7 mm.

In order to evaluate the relations between Inf_c, FDZ and droplet size, the procedure above was followed for all droplet sizes. This resulted into a first order relation between Inf_c and droplet diameter (d) and this equation is used for selecting only the focused droplets in a real spray application:

$$Inf_c = 0.017 * d + 2.04 \tag{2}$$

3. Results and Discussion

3.1. Spray droplet characterization using the in-focus droplet criterion

A similar set-up as described in Fig. 1 was used for the spray droplet characterization. The nozzle was always set between the lens and light source. In this study, five different hydraulic spray nozzles were selected: two hollow cone (ATR orange, ATR red), two standard flat fan (XR 110 01, XR 110 04) and one air inclusion flat fan (AI 110 04). Images were acquired at 500 mm below the nozzle at three different positions: in the centre, at 200 mm and at the edge of the spray.

Furthermore, the spray image analysis (Fig. 4) consisted of different steps: image pre-processing, image segmentation and droplet sizing and selection based on the in-focus criterion (Eq. 2). Droplets having an in-focus parameter bigger than the corresponding Inf_cwere considered in focus and included in the spray distribution results. All other droplets were rejected and not further used in the analysis.

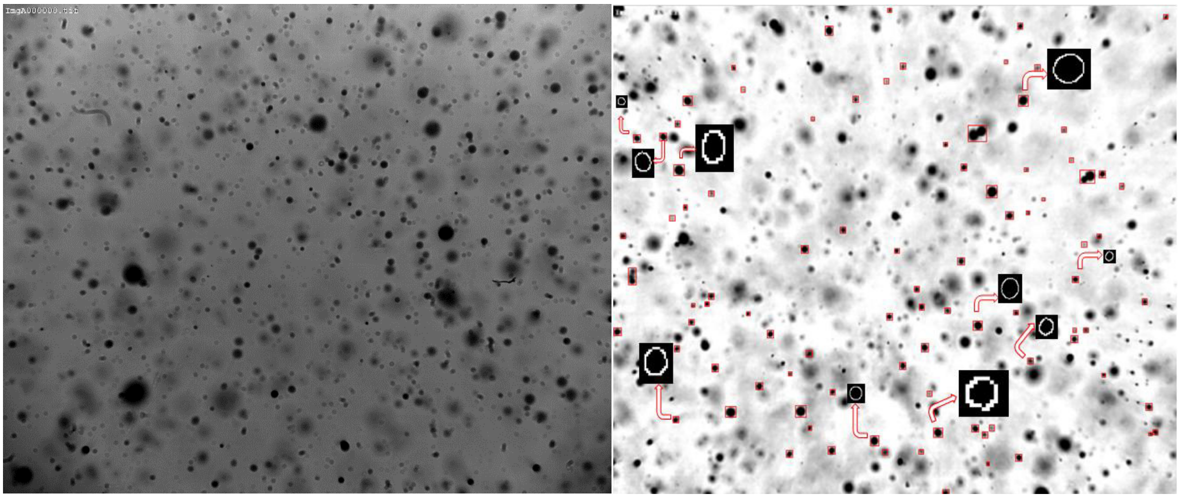

Fig. 4.Example of spray droplet image with XR 110 04 nozzle at 400 kPa in the centre(left) before image analysis and (right) after image segmentation.

3.2. Spray droplet size distribution

Fig. 5 presents the cumulative droplet size distributions below the nozzles for the five nozzle-pressure combinations. In the centre of the spray, finest droplet size spectra were found for the hollow cone nozzles (ATR orange and red) followed by the standard flat fan nozzles (XR 110 01 and 110 04) while the coarsest droplets were found for the air inclusion flat fan nozzle (AI 110 04) which confirms previous results from, among others, Nuyttenset al. (2007, 2009).The difference between the ATR orange at 600 kPa and the ATR Red at 800 kPa was limited which confirms the PDPA results published by Dekeyseret al. (2013).Similarly, no differences were found in measured droplet sizes between the XR 110 01 and the XR 110 04 nozzle at this position.

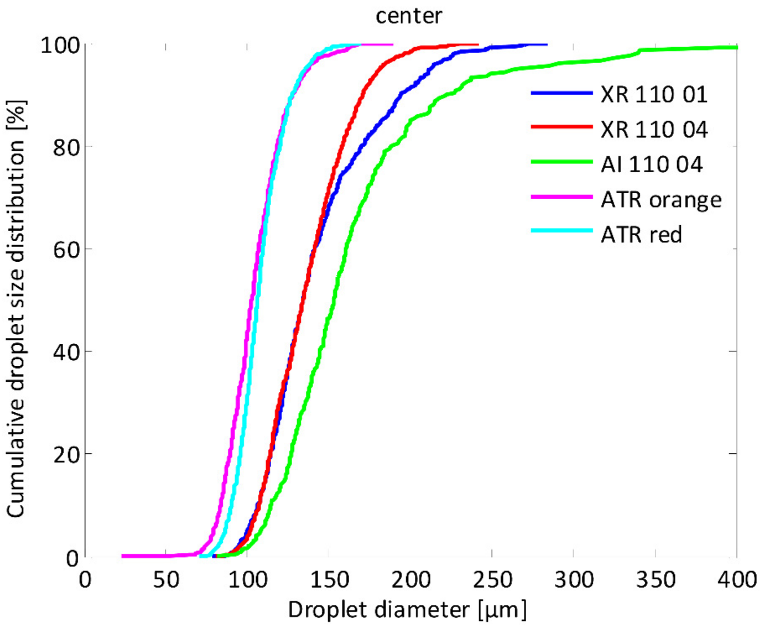

Fig. 5.Cumulative droplet size distributions below the nozzles for the five nozzle – pressure combinations.

4. Conclusions

This paper presents a technique based on image processing for measuring the droplet size of agricultural hydraulic spray nozzles using developed image acquisition system. Differently sized droplets generated with a droplet generator and glass nozzles in continuous mode at different distances from the focal plane and lens using a micro translation stage were measured. From this, a critical in-focus parameter (Inf_c) was established for every droplet size and an in-focus droplet criterion was deduced to decide whether a droplet is in focus or not depending on its diameter and in-focus diameter. Afterwards, the in-focus droplet criterion was applied to spray images of different hydraulic nozzles and the droplet size characteristics were calculated. The droplet size results from the imaging technique have shown that is possible to measure the spray droplet characteristics in a non-intrusive way using image acquisition set-up and image processing.

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